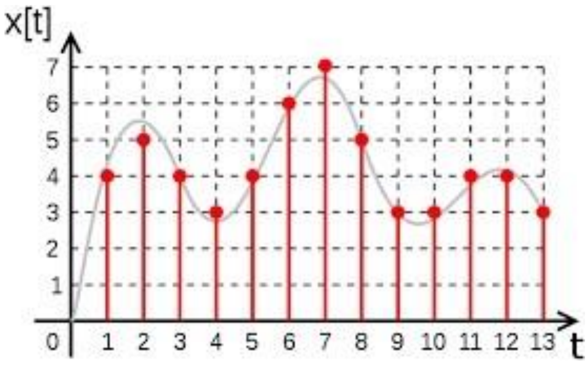
Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

[RE-47] DISCRETE AND DIGITAL SIGNALS AND PROCESSES IN RADIO ENGINEERING



Curriculum (Syllabus)

Course details

Level of higher education	First (bachelor's)
Field of knowledge	17 - Electronics, Automation, and Electronic Communications
Specialization	172 - Electronic Communications and Radio Engineering
Educational program	All educational programs
Discipline status	Elective (F-catalog)
Form of higher education	Full-time
Year of training, semester	Available for selection starting from the 1st year, spring semester
Scope of the discipline	4 credits (Lectures 18 hours, Practical classes 36 hours, Laboratory work 36 hours, Independent work 66 hours) Semester
Control/control measures	Credit
Class schedule	https://schedule.kpi.ua
Language of instruction	Ukrainian
Information about the course coordinator/teacher s	Lecturer: Pavlov O. I., Lab: Pavlov O. I., SRC: Pavlov O. I.

Course location http:\\dtsp.kiev.ua

Curriculum

1. Description of the course, its purpose, subject matter, and learning outcomes

The discipline "Discrete and Digital Signals and Processes in Radio Engineering" (hereinafter referred to as DDSPRE) belongs to the cycle of professional training of specialists of the first (bachelor's) level of higher education in the specialty 172 "Electronic Communications and Radio Engineering," is selective (non-mandatory) and, according to the OP "Information and Communication Radio Engineering," has the code PF 01-14 as a selective educational component of the F-catalog with the code RE-47.

I.1 Subject and purpose of the discipline

The subject of the discipline "Discrete and Digital Signals and Processes in Radio Engineering" (DCDSPE) is the properties and methods of analysis and synthesis of discrete-time signals and discrete systems, as well as the features of their application in radio engineering, including radio communication, radar, hydroacoustics, seismology, the design of radio engineering and mechanical systems, navigation, and medical electronics.

The aim of the discipline is to develop students' competence in:

- performing time, spectral, and correlation analysis of deterministic signals in discrete time and random signals in continuous and discrete time using the Matlab system;
- performing calculations of time and spectral characteristics of discrete LSS;
- performing calculations of LSS response in time and spectral space;
- conducting experimental research on digital modulation and demodulation processes, as well as methods of high-resolution parametric CSA.

After completing the course, students should demonstrate the following learning outcomes:

KNOWLEDGE (the result of studying the phenomena and patterns of the objective world, which can be logically or factually justified and empirically or practically verified):

- classification of discrete signals and systems, their definitions, properties, and criteria; properties of the discrete convolution process as the main process of signal conversion in DSS;
- features of representing discrete LSS in the form of LRRPC; the essence of DCT as a method of frequency representation of signals and systems and its properties; the essence of Z-transform as a generalization of DCT and its properties;
- processes of discretization and restoration of continuous signals and their properties in NDN and DND systems; processes of discretization with increased and decreased frequencies used in multiple signal processing systems;
- rules for representing discrete LSSs described by LRRPCs using characteristic functions and using a map of zeros and poles; methods of LSS analysis; the concept of group delay in the analysis of phase distortions; the relationship between the frequency response and amplitude response of discrete systems, including minimum phase, all-pass, and generalized linear phase systems;
- the essence of DRF and DFT, their properties and the relationship between them and with DCT and NCT; the essence of DCP and its properties; the method of calculating discrete convolution using DCT; rules for applying DCT to Fourier analysis of signals; the essence of time-dependent DCT; the effects of window processing; the essence of periodogram and correlogram analysis;
- fundamentals of general theory of random signals; principles of random signal processing by linear stationary, parametric, and nonlinear systems; theory of optimal filtering of random signals;

SKILLS (ability to perform activities, "trained to perform actions," formed by repeating an action and bringing it to automatism):

- performing time, spectral, and correlation analysis of deterministic signals in discrete time and random signals in continuous and discrete time using the Matlab system;

• calculating the time and spectral characteristics of discrete LSS; • calculating the response of LSS in time and spectral space;
• experimental study of digital modulation and demodulation processes, as well as methods of high-resolution parametric CSA.

SKILLS (a mastered method of performing an action, which is ensured by a set of acquired knowledge and skills**,** and which creates the possibility of performing an action not only in familiar conditions, but also in changed ones):

• perform correlation and spectral analysis of discrete and random signals;
• perform calculations of the main temporal and spectral characteristics and parameters of discrete LSS;
• perform calculations of the response of discrete LSS to the action of deterministic and random signals using time and spectral methods; determine the characteristics of random signals at the output of such systems.

After mastering the course, students should demonstrate program competencies (a range of topics in which they have good knowledge) and learning outcomes in accordance with the educational and professional program "*Information and Communication* Radio Engineering" (see the website https://osvita.kpi.ua/op), including, but not limited to (according to the educational and professional program introduced in the 2023/2024 academic year by order of the rector of Igor Sikorsky Kyiv Polytechnic Institute No. MOM/165/2023 dated May 17, 2023):

General competencies

GC 1 — Ability to think abstractly, analyze, and synthesize (spectral and multidimensional representation of signals in different bases, representation of finite signals by infinite functions, application of the theory of complex variable functions, modeling of processes and systems, etc. — actual knowledge of the essence of the issues studied and the approaches applied).

GC 2 — Ability to apply knowledge in practical situations.

GC 4 — Ability to understand the subject area and professional activity (knowledge of the purpose and structure of modern radio engineering and telecommunications systems, the processes that take place in them, etc.).

GC 7 — Ability to learn and acquire modern knowledge.

GC 8 — Ability to identify, pose, and solve problems.

Professional competencies

PC 3 — Ability to use basic methods, techniques, and tools for obtaining, transmitting, processing, and storing information.

PC 4 — Ability to perform computer modeling of devices, systems, and processes using universal application software packages.

Program learning outcomes

PLO 6 — Competently apply terminology in the field of telecommunications and radio engineering.

PLO 7 — Describe the principles and procedures used in telecommunications systems, information and telecommunications networks, and radio engineering.

PLO 12 — apply fundamental and applied sciences to analyze and develop processes occurring in telecommunications and radio engineering systems.

2. Prerequisites and post-requisites of the discipline (place in the structural-logical scheme of training under the relevant educational program)

2.1. The study of the academic discipline DDSPRE is based on the competencies acquired during the study of the following academic disciplines: "Higher Mathematics" (topics "Differentiation and Integration of Functions," "Functional Series," "Differential Equations," "Fourier Transform," "Probability Theory," "Theory of Complex Variable Functions"), "Physics" (topics "Electrostatics," "Electromagnetism"), "Materials and Components of Radio-Electronic Equipment" or "Circuit Engineering. Part 1. Electronic Component Base" (topic "Characteristics of Electronic and Semiconductor Devices"), "Circuitry. Part 2. Analog Circuitry" (topics "Elementary Amplifiers on Bipolar and Field-Effect Transistors," "Transistor Operation in Nonlinear Mode"), "Fundamentals of Circuit Theory" (topics "Oscillatory Circuits," "Coupled Circuits," "Circuit Functions").

2.2. The competencies acquired during the study of DDSPRE are used in the study of all subsequent disciplines of specialty 172 "Electronic Communications and Radio Engineering" without exception, as well as during the implementation of the diploma project.

3. Contents of the academic discipline

Section 1. Discrete signals and discrete systems [1, Chapter 2. pp. 28-110]
Topic 1.1. Discrete signals as sequences
Introductory provisions (Signal classification: LF and MF signals. AA and CA signals. Digital signals. The difference between discrete signal processing (DSP) theory and digital signal processing (DSP). The self-sufficiency of DSP theory and the main stages of its development. Parallel study of DSP theory and analog signal and process theory (SPRT KM1, OTTK). DSP as a superstructure over DSP. Basic world literature on DSP and DSP theory.
Discrete signals as sequences (Step and sampling frequency. The concept of sampling a continuous-time signal and its reconstruction according to Nyquist. [1, pp. 28–30]. Standard sequences and operations on them (Combining standard sequences. Periodic and non-periodic discrete sinusoids) [1, pp. 30–35].
Thematic test 1 on topic 1.1 (*Moodle*).
Topic 1.2. Types of discrete systems and their definition through discrete signal conversion processes
Memoryless and memory systems. Linear and nonlinear systems. Stationary (time-invariant) and nonstationary systems. Deterministic and non-deterministic systems. Stable and unstable systems. Ideal delay system. Moving average. Accumulator. Quadratic and logarithmic systems. Compressor. Right and left difference systems. Verification of linearity, determinism, stability. [1, pp. 35–42].
Thematic test 2 on topic 1.2 (*Moodle*).
Topic 1.3. Discrete convolution as a process of signal conversion in linear stationary systems Linear time-invariant (LTI) systems. Conditions and consequences of linearity. Conditions and consequences of stationarity. Impulse response of a system. Description of signal conversion in linear time-invariant (LTI) systems using discrete convolution [1, pp. 42–47].
Topic 1.4. Properties of the discrete convolution process and linear stationary systems Commutativity, distributivity, and associativity of the discrete convolution process. Equivalent representation of serial and parallel connections of LSI systems. [1, pp. 47–53]. Thematic test 3 on topics 1.3 and 1.4 (*Moodle*).
Topic 1.5. Representation of discrete signal conversion processes in linear stationary systems as linear difference equations with constant coefficients
Linear difference equation with constant coefficients (LDC). The relationship between the input and output sequences of the LDC and its graphical representation in the form of a "zipper" block diagram. The explicit form of the LDC relative to the newest and oldest samples of the output sequence. Block diagram of a discrete system in the form of transverse and recursive parts. LRRPC for a storage device and a moving average.
Solution of LRRPC (Representation of the LRRPC solution as partial and homogeneous. Homogeneous equation. Characteristic algebraic equation. General form of a homogeneous solution in the absence of multiple roots. Additional conditions for solving the LAR system when determining a homogeneous solution. Recursive method for calculating the output sequence. Example of solving LRRPC for a nonlinear, non-deterministic, and non-stationary system. Simultaneous requirements for linearity, determinism, and stationarity. Steady state in the initial position. [1, pp. 53–59, 96–98].
Thematic test 4 on topic 1.5 (*Moodle*).
Topic 1.6. Representation of discrete signals and processes in discrete-time systems in the frequency domain
Complex exponent as an intrinsic function and BPP as an intrinsic value of a discrete linear stationary system. BPP of an ideal delay system. Sinusoidal representation of LSS. Periodicity of the transfer function. Frequency response and phase response. Lower and upper frequencies. Transfer function of an ISZ, ideal LPF, ideal HPF, ideal passband and bandpass filters. Transfer function of a moving average, Dirichlet function.
Steady-state and transient responses of a discrete linear stationary deterministic system to an instantaneously applied discrete complex exponent. [1, pp. 59–67].

Topic 1.7. Discrete-time Fourier transform (DTFT)
Forward DFT, calculation interval, periodicity and continuity (density) of the Fourier image by frequency. Amplitude and phase spectra of a discrete signal. Relationship between IH and KCH of LSS. Representation of a delta impulse as an integral of a complex exponential signal of DT. Decomposition of a DT signal into a superposition of delayed delta impulses and the inverse DTFT formula.
Conditions for the existence of a Fourier image. Absolute summation of a signal and uniform convergence of a series of partial sums to a Fourier image. Summation by squares and mean square convergence of a series. Gibbs effect for the frequency response of an ideal low-pass filter.
Fourier images of signals that are neither absolutely nor quadratically summable. Dirac function of continuous argument, its properties. Fourier images of a constant sequence, complex exponential sequences, and a unit jump. [1, pp. 67–74].
Thematic test 5 on topics 1.6 and 1.7 (*Moodle*). Topic 1.8. Symmetries of the DCT
Conjugate-symmetric and conjugate-skew-symmetric sequences. Even and odd sequences. General properties of FFT symmetry for arbitrary sequences. Properties of FFT symmetry for real sequences [1, pp. 74–77].
Thematic test 6 on topics 1.7 and 1.8 (*Moodle*). Thematic test 7 on topic 1.7 (*Moodle*).
Thematic test 8 on topics 1.8 (*Moodle*). Topic 1.9. Theorems about DFT
Linearity of DCPF. Time and frequency shifts. Time reversal. Differentiation in the frequency domain. Parseval's theorem. Theorem on discrete convolution. Modulation, or theorem on discrete periodic convolution. [1, pp. 77–83].
Thematic test 9 on topic 1.9 (*Moodle*).

Topic 1.10. Random discrete signals
An ensemble of DC signals characterized by multiple probability densities. The concept of a stochastic signal and a random process (RP). The non-guaranteed summability of random signals, either absolutely or by squares, and the non-guaranteed existence of their Fourier images.
Description of SP using statistical characteristics. Non-stationarity, stationarity in the narrow and broad sense. Mean value (mathematical expectation), autocorrelation function (ACF), and autocovariance function of SP. Differences between international and domestic terminology.
The relationship between the input and output ACF of the LSS using the discrete convolution formula, the deterministic aperiodic autocorrelation sequence (AAC) of the IX LSS.
Spectral power density (SPD) of the input and output of the LSS, the relationship between them through the LSS frequency response. Properties of SPD.
Mutual correlation sequence (MCS) of the input and output of the LSS as a discrete convolution of the IX LSS and the ACS of the input.
White noise, its SPD, and the SPD of noise at the output of the LSS. [1, pp. 83–88]. Module test 1 for section 1 (*Moodle*).
Modular test 2 on section 1 (*Moodle*).

Section 2. Z-transformation [1, Chapter 3. pp. 111–153]
Topic 2.1. Direct bilateral Z-transformation
Laplace transform for continuous-time signals. Complex plane of the operator method. Laurent series and bilateral Z-transform. Relationship between Z-transform and DFT. Complex plane in the Z-transform method and unit circle in the DFT method. Concept of convergence region (CR) of Z-transform. Form of CR boundaries. Criterion for existence of Z-image.
Representation of the Z-transform by a rational function. The concept of zeros and poles of the Z-transform. Map of zeros and poles, Z-transform, and CO for right-sided and left-sided exponential sequences. Sum of two exponential sequences (different cases). [1, pp. 111–120].
Topic 2.2. Region of convergence of the Z-transform
Form of LO. Criterion for the existence of the DCT through the LO of the Z-transform. Poles of the Z- form and its OZ. OZ of the Z-transform of a bounded signal of finite duration. OZ of the Z-transform of a right-sided sequence. OZ of the Z-transform of a left-sided sequence. OZ of the Z-transform of a bilateral sequence. Connectivity of OZ.
Table of Z-transform and OZ for some signals. Stability, determinism, and OZ. [1, pp. 120–127]. Topic 2.3. Inverse Z-transform
Tabular method. Method of simple fractions. Device for rational functions of the 2nd degree. Decomposition formulas for different cases. Expansion into power series. Sequences of finite length. [1, pp. 127–134].
Topic 2.4. Properties of Z-transformation
Linearity. Delay. Multiplication by an exponential sequence. Differentiation in time space. Conjugation of a complex sequence. Time reversal. Convolution of a sequence. Initial value theorem. [1, pp. 134–142]. Modular test on Section 2 (*Moodle*).

Section 3. Discretization of a continuous signal [1, Chapter 4. pp. 154–253]
Topic 3.1. The process of periodic discretization of a continuous signal.

Periodic discretization. Discretization step. Discretization frequency. Ideal continuous-discrete transformation (CDT). [1, pp. 154–156].
Topic 3.2. Frequency representation of the sampling process
Multiplicative modulation of a continuous signal by a periodic chain of Dirac delta functions and convolution of their Fourier images (NCHF) in frequency space. Periodic repetition of spectra. Superposition of spectra, their distortion, and the appearance of spurious frequencies at different sampling frequencies.
Nyquist's theorem. Nyquist frequency. The relationship between the Fourier image of the DCT and the Fourier image of the FFT. Anti-aliasing filtering of real signals before discretization.
Discretization and reconstruction of a sinusoidal signal. Subdiscretization. Superposition of spectra during the reconstruction of a sinusoidal signal. [1, pp. 156–162].

Topic 3.3. The process of restoring a narrowband continuous signal based on its readings
IX ideal continuous low-pass filter for signal restoration. Interpolation of discrete signal values between readings. Discrete signal readings as weighting coefficients of ideal reconstructive orthogonal basis functions of Nyquist in the inverse Nyquist transform (inverse generalized PF in the Nyquist basis), and as a result of the direct Nyquist transform from a continuous signal (direct generalized PF in the Nyquist basis). Ideal discrete-to-continuous converter (DCC). [1, pp. 162–166].
Topic 3.4. Processes of transforming spectrum-limited continuous signals in DCT-DS-DCT (DCT) systems
Discrete processing of continuous signals and structural diagram of an NDN system. Application of LSS in NDN systems. Effective frequency response of a virtual continuous LSS equivalent to an NDN system. Ideal continuous LPF with built-in discrete filter.
Discrete implementation of an ideal continuous narrowband differentiator. Pulse invariance of a continuous LSS and an equivalent DSP system.
Impulse invariance, continuous LPF, and equivalent discrete LPF.
Pulse invariance and continuous systems with rational system functions. [1, pp. 166–175].
Topic 3.5. Processes of converting discrete signals in DNP-NS-NDP (DND) systems Continuous processing of discrete signals, block diagram of a DND system, and basic equations of its operation. Non-integer delay. Moving average with non-integer delay. [1, pp. 175–179].
Topic 3.6. Changing the sampling frequency of a signal without restoring its continuous form. Reducing the sampling frequency by an integer number of times. Increasing the sampling frequency by an integer number of times. Changing the sampling frequency by a rational factor. [1, pp. 179–190].
Topic 3.7. Processes of converting continuous signals with variable sampling frequency (multi-speed signals) Changing the order of spectrum limiting processes and lowering/raising the sampling frequency. The process of multiphase decomposition of a discrete signal. Multiphase implementation of the thinning process. Multiphase implementation of the interpolation process. [1, pp. 190–197].
Topic 3.8. Processes of converting unlimited analog signals in ND systems Preliminary spectrum limitation to eliminate the overlapping effect. Conversion of analog continuous signal into a digital signal. Analysis of quantization errors. Conversion of a digital signal into an analog continuous signal. [1, pp. 197—214].
Topic 3.9. High-frequency sampling processes and noise generation in ADCs and DACs ADC process with high sampling frequency and simple quantization. The process of ADC with increased sampling frequency and noise generation. The process of DAC with increased sampling frequency and noise generation. [1, pp. 214–227].
Modular test for section 3 (*Moodle*).

Chapter 4. Analysis of processes in linear stationary discrete-time systems [1, Chapter 5. pp. 254-345]
Topic 4.1. Complex frequency response of a discrete linear stationary system Ideal spectrum limitation. Phase distortion and delay. [1, pp. 254–258].
Topic 4.2. Characteristic functions of systems represented by linear difference equations with constant coefficients
Stability and determinism. Inverse systems. Impulse response of discrete systems with rational characteristic function. [1, pp. 258–267].
Topic 4.3. Transfer function of discrete systems with a rational characteristic function
Transfer function in the case of a single zero or pole of the characteristic function. Examples with multiple poles or zeros. [1, pp. 267–281].
Topic 4.4. Relationship between ACF and FCF
The concept of minimum phase. Inverse transformation of a complex plane with respect to a unit circle. [1, pp. 281–285].
Topic 4.5. Discrete systems with constant frequency response Systems with constant frequency response of the 1st and 2nd order. [1, pp. 285–290]. Topic 4.6. Minimum-phase discrete systems
Decomposition of complex systems into minimum-phase and constant frequency response systems. Compensation for frequency response distortions in discrete linear stationary systems. Properties of minimum-phase systems. [1, pp. 290–300]

Topic 4.7. Discrete linear systems with generalized linear phase
Systems with linear phase. Generalization of linear phase. Deterministic systems with generalized linear phase. Relationship between linear-phase SIH systems and minimum-phase systems. [1, pp. 300–318].
Modular test on Section 4 (*Moodle*).

Section 5. Discrete Fourier Transform [1, Chapter 8. pp. 548-629] Topic 5.1.
Discrete Fourier Series: Representation of Periodic Sequences
Representation of periodic sequences of DC through discrete Fourier series (DFS). A finite number of periodic complex exponents of DC with the same period and finiteness of DFS terms. Determination of decomposition coefficients (analysis equation). An infinite number of periodic values of DC frequencies leading to the same periodic complex exponents, periodicity of the sequence of decomposition coefficients. Restoration of a periodic DC signal using DFT coefficients (synthesis equation).
DFT of a periodic chain of unit pulses. Duality of the form of the DC sequence and the form of the DFT coefficient sequence. DFT of a periodic sequence of rectangular pulses. [1, pp. 548—552].
Topic 5.2. Properties of DRF
Linearity. Sequence shift. Duality of time and frequency space. Symmetry. Periodic convolution. Overview of the properties of representing periodic sequences in the form of DFT. [1, pp. 552–557].
Topic 5.3. Fourier transform of periodic signals
Representation of FFT coefficients as a line spectrum only at discrete frequencies. Non-summability of periodic signals either absolutely or by squares, and the absence of their DFT. Application of the Dirac delta function with a continuous argument for the conditional representation of periodic signals in the form of a continuous and periodic Fourier image in terms of frequency. The inverse DFT of the proposed conditional Fourier image of periodic signals. DFT for a periodic chain of unit pulses. Periodic extension of a finite duration (FD) signal. Consideration of the periodic sequence of DRF coefficients of the periodically extended signal ST as a result of uniform discretization of the Fourier image of the primary signal ST. The relationship between the DRF coefficients and the DFT function of one signal period. [1, pp. 557–561].
Topic 5.4. Discretization of the Fourier image
The Fourier image of an arbitrary non-periodic signal DC as an FSG that is continuously defined on a unit circle of the complex plane. Dividing the unit circle into N parts and defining the FSG at the vertices of the inscribed regular N-gon with the formation of a periodic sequence of values — the coefficients of the DRF of a given periodic signal DC — the result of the superposition of the periodic repetition of the original non-periodic signal. Equivalent description of the process of discretization of the Fourier image through discrete convolution of a non-periodic signal and a periodic sequence of single pulses. The frequency of discretization of the Fourier image and the conditions for undistorted periodic continuation of the signal. [1, pp. 561–565].
Topic 5.5. Discrete Fourier transform as a method of representing sequences of finite duration Undistorted periodic extension of CT sequences. Representation of the obtained periodic extension of the signal as a finite set of DRF coefficients, — DFT coefficients. DFT coefficients as an estimate of the FSG of the Fourier image of the CT signal at the vertices of a regular N-gon inscribed in a unit circle. Formulas for forward and inverse DFT. Interpolation of DFT coefficients by increasing the vertices of the N-gon (repeating the CT signal with a longer period). DFT of a rectangular pulse. [1, pp. 565–569].
Topic 5.6. Properties of DFT
Linearity. Cyclic shift of the sequence. Duality of time and frequency space. Symmetry. Cyclic convolution. Overview of the properties of representing periodic sequences as DFTs. [1, pp. 569–580].
Topic 5.7. Calculation of linear convolution using DFT
Linear convolution of two finite sequences. Cyclic convolution as linear with the effect of overlapping samples in time. Implementation of discrete linear stationary systems via DFT. [1, pp. 580–591].
Topic 5.8. Discrete cosine transform
Definition of discrete cosine transform. Definition of DCT-1 and DCT-2. Relationship between DFT and DCT-1. Relationship between DFT and DCT-2. Energy compression in DCT-2. Application of DCT. [1, pp. 591—602].
Modular test on Section 5 (*Moodle*).

Section 6. Application of DFT to Fourier analysis [1, Chapter 10. pp. 695-777]
Topic 6.1. DFT and Fourier analysis of signals
Stages of continuous signal processing using DFT analysis. Imperfection of the anti-aliasing filter. Jitter during discretization. Quantization noise. Purpose and use of weighting windows. Spectrum spreading, side lobe level from the window function. Fourier analysis using DFT. [1, pp. 695-699].
Topic 6.2. DFT analysis of harmonic signals
The effect of window processing. Spectral discretization. Effects of spectral discretization. [1, pp. 699–715].
Topic 6.3. Time-dependent DFT
The effect of window processing in the ZF DFT. Discretization in time and frequency. [1, pp. 715–723]. Topic 6.4. Block convolution using the ZF DFT [1, pp. 723–724].
Topic 6.5. Fourier analysis of non-stationary signals
Time-dependent Fourier analysis of speech signals. Time-dependent Fourier analysis of radar signals. [1, pp. 724–730].
Topic 6.6. Fourier analysis of stationary random signals: periodogram
Periodogram. Properties of periodograms. Averaging periodograms. Calculating averaged periodograms using DFT. Example of periodogram analysis. [1, pp. 730–743].
Topic 6.7. Spectral analysis of random signals using autocorrelation function estimates Calculating correlation and estimating the power spectrum using DFT. Example of power spectrum estimation using autocorrelation sequence estimation. [1, pp. 743–755].
Modular test for Section 6 (*Moodle*).

Section 7. Discrete Hilbert transform [1, Chapter 11. pp. 778-813]
Topic 7.1. Introductory provisions. [1, pp. 778–720].
Topic 7.2. Real and imaginary parts of the Fourier image of a deterministic sequence. [1, pp. 780–785].

Topic 7.3. Sufficiency theorems for finite sequences. [1, pp. 785–791]. Topic 7.4. The relationship between absolute value and phase. [1, pp. 791–792].
Topic 7.5. The relationship between the real and imaginary parts of analytic sequences via the Hilbert transform
Designing a Hilbert transform. Representation of band signals. Band discretization. [1, pp. 792–804]. Modular test for Section 7 (*Moodle*).

4. Teaching materials and resources

Recommended reading:

Main

1. Oppenheim A. Schafer R. Discrete Time Signal Processing - 1998. - 870 p. (Parts of book)
2. Oppenheim A. Schafer R. Discrete Time Signal Processing. Solutions - 1998. - 488 p.
3. Oppenheim, A. V., Shafer, R. V. Signal Processing in Discrete Time: Translated from English. S. A. Kuleshova / Edited by A. S. Nenashov. — 2006. — 856 p. (Selected parts of the book)
4. Oppenheim A. Schafer R. Discrete Time Signal Processing - 2009. - 1108 p.

Additional

5. Buck, Singer. Computer Explorations in SIGNALS AND SYSTEMS using Matlab
6. McClellan. Computer-Based Exercises for Signal Processing Using MATLAB
7. Stearns. Digital Signal Processing with Examples in MATLAB
8. Alan V. Oppenheim, Alan S. Willsky, S.Hamid. Signals and Systems, - 2nd ed. - Prentice-Hall, 1996.
9. - 957 p.
10. Marple, S.L. (1990) Digital spectral analysis and its applications (547 p.)
11. Jenkins G. Watts D. (1971) 1. Spectral Analysis and Its Applications
12. Jenkins G., Watts D. (1972) 2. Spectral Analysis and Its Applications
13. Voloshchuk Yu.I. Signals and Processes in Radio Engineering (Part 1)
14. Voloshchuk Yu.I. Signals and processes in radio engineering (part 2)
15. Voloshchuk Yu.I. Signals and processes in radio engineering (part 3)
16. Voloshchuk Yu.I. Signals and processes in radio engineering (part 4)
17. Sklyar B. (2003) Digital Communications. Chapter 1. Signals and Spectra
18. Shryufer E. Digital Processing of Discrete Signals (1992)
19. Sergienko, A. B. Digital Signal Processing (2002) — 608 p.

Manuals and methodological guidelines

1. Methodological guidelines "Spectral transformations and CSA methods" for the discipline "Discrete and digital signals and processes in radio engineering." For students of the Radio Engineering Faculty of all forms of training / Compiled by O. I. Pavlov, — Kyiv: NTUU "KPI," 2020. — 45 p.
2. Modeling of signals and processes in radio engineering in MathCAD and Multisim environments. Part I. [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Compiled by: O.V. Guseva, O.I. Pavlov; Igor Sikorsky KPI. — https://drive.google.com/file/d/1dHixDBS0UNpgukc3Lrnxe5KuBmEHwdxj/view?usp=sharing
3. Modeling of signals and processes in radio engineering in MathCAD and Multisim environments. Part 2. [Electronic resource]: textbook for students majoring in 172 Telecommunications and Radio Engineering / Compiled by: O.V. Guseva, O.I. Pavlov; Igor Sikorsky Kyiv Polytechnic Institute. — Electronic text data (1 file, 3.173 MB). — Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2022. — 109 p. — https://drive.google.com/file/d/19IsfgO4dEm2i9C7bvV2PiGwgZmZPqV2k/view?usp=sharing
4. Modeling of signals and processes in radio engineering in MathCAD and Electronics Workbench environments. Part I [Electronic resource]: textbook for students majoring in 172 "Telecommunications and Radio Engineering" / Compiled by: O. V. Guseva, O. I. Pavlov; Igor Sikorsky Kyiv Polytechnic Institute. — Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. — 128 p. — https://ela.kpi.ua/handle/123456789/43832

Information resources

1. SDN server of the Department of TOR for the discipline SPRT at dtsp.kiev.ua (electronic versions of literature, methodological guidelines, tasks, ratings).

Educational content

5. Methodology for mastering the academic discipline (educational component)

5.3. Lectures

The structure of the lectures for a total of 36 hours is shown in the table.

No.	Lecture topic and list of main questions (list of teaching aids, references to literature, and assignments for independent study)	Number of hours
	Section 1. Discrete signals and discrete systems	
1	Topic 1.1. Discrete signals as sequences Introductory provisions (Classification of signals: LF and HF signals. AA and CA signals. Digital signals. The difference between discrete signal processing (DSP) theory and digital signal processing (DSP). The self-sufficiency of DSP theory and the main stages of its development. Parallel study of DSP theory and analog signal and process theory (SPRT KM1, OTTK). DSP as a superstructure over DSP. Basic world literature on DSP and DSP theory. Discrete signals as sequences (Step and sampling frequency. The concept of sampling a continuous-time signal and its reconstruction according to Nyquist. [1, pp. 28–30]. Standard sequences and operations on them (Combining standard sequences. Periodic and non-periodic discrete sinusoids) [1, pp. 30–35].	0.25
	Topic 1.2. Types of discrete systems and their definition through discrete signal conversion processes Systems with and without memory. Linear and nonlinear systems. Stationary (time-invariant) and nonstationary systems. Deterministic and non-deterministic systems. Stable and unstable systems. Ideal delay system. Moving average. Accumulator. Quadratic and logarithmic systems. Compressor. Right and left difference systems. Verification of linearity, determinism, stability. [1, pp. 35–42].	0.25

	Topic 1.3. Discrete convolution as a process of signal transformation in linear stationary systems Linear stationary (LSI) systems. Conditions and consequences of linearity. Conditions and consequences of stationarity. Impulse response of a system. Description of signal conversion in linear stationary (LSI) systems using discrete convolution [1, pp. 42–47].	0.75
	Topic 1.4. Properties of the discrete convolution process and linear stationary systems Commutativity, distributivity, and associativity of the discrete convolution process. Equivalent representation of serial and parallel connections of LSI systems. [1, pp. 47–53].	0.75
—	**Total**	**2.00**
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1	Topic 1.5. Representation of discrete signal conversion processes in linear stationary systems in the form of linear difference equations with constant coefficients Linear difference equation with constant coefficients (LDC). The relationship between the input and output sequences of the LDC and its graphical representation in the form of a "zipper" block diagram. The explicit form of the LDC relative to the newest and oldest samples of the output sequence. Block diagram of a discrete system in the form of transverse and recursive parts. LRRPC for a storage device and a moving average. Solution of LRRPC (Representation of the LRRPC solution as partial and homogeneous. Homogeneous equation. Characteristic algebraic equation. General form of a homogeneous solution in the absence of multiple roots. Additional conditions for solving the LAR system when determining a homogeneous solution. Recursive method for calculating the output sequence. Example of solving LRRPC for a nonlinear, non-deterministic, and non-stationary system. Simultaneous requirements for linearity, determinism, and stationarity. Steady state in the initial position. [1, pp. 53–59, 96–98].	0.75
	Topic 1.6. Representation of discrete signals and processes in discrete-time systems in the frequency domain Complex exponent as an eigenfunction and BPP as an eigenvalue of a discrete linear stationary system. BPP of an ideal delay system. Sinusoidal representation of LSS. Periodicity of the BPP. ACP and FCP. Lower and upper frequencies. BPP of ISZ, ideal LPF, ideal HPF, ideal passband and delay filters. BPP of the moving average, Dirichlet function. Steady-state and transient responses of a discrete linear stationary deterministic system. systems to an instantaneously switched discrete complex exponent. [1, pp. 59–67].	0.50
	Topic 1.7. Discrete Fourier transform (DFT) Forward DFT, calculation interval, periodicity and continuity (density) of the Fourier image by frequency. Amplitude and phase spectra of a discrete signal. Relationship between IH and KCH of LSS. Representation of a delta impulse as an integral of a complex exponential DT signal. Decomposition of a DT signal into a superposition of delayed delta impulses and the inverse DFT formula. Conditions for the existence of a Fourier image. Absolute summation of a signal and uniform convergence of a series of partial sums to a Fourier image. Summation by squares and mean square convergence of a series. Gibbs effect for the KCH of an ideal LPF. Fourier images of signals that are neither absolutely nor quadratically summable. The Dirac function of continuous argument, its properties. Fourier images of a constant sequence, complex exponential sequences, and a unit jump. [1, pp. 67–74].	0.75
—	**Total**	**2.00**
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1	Topic 1.8. Symmetries of DCT Conjugate-symmetric and conjugate-skew-symmetric sequences. Even and odd sequences. General properties of DCPF symmetry for arbitrary sequences. Properties of DCPF symmetry for real sequences [1, pp. 74–77].	0.50
	Topic 1.9. Theorems about DCPF Linearity of the DFT. Time and frequency shifts. Time reversal. Differentiation in the frequency domain. Parseval's theorem. Discrete convolution theorem. Modulation, or discrete periodic convolution theorem. [1, pp. 77–83].	0.75
	Topic 1.10. Random discrete signals An ensemble of DC signals characterized by multiple probability densities. The concept of a stochastic signal and a random process (RP). The unguaranteed summability of random signals, either absolutely or by squares, and the unguaranteed existence of their Fourier images. Description of a CP using statistical characteristics. Non-stationarity, stationarity in the narrow and broad sense. Mean value (mathematical expectation), autocorrelation function (ACF), and autocovariance function of a CP. Differences between international and domestic terminology. The relationship between the ACF of the input and output of the LSS by the discrete convolution formula, the deterministic aperiodic autocorrelation sequence (ACS) of the LSS. Spectral power density (SPD) of the input and output signals of the LSS, the relationship between them through the LSS frequency response. Properties of SPD. Mutual correlation sequence (MCS) of the input and output of the LSS as a discrete convolution of the IX LSS and the autocorrelation sequence of the input. White noise, its SSP, and the SSP of noise at the output of the LSS. [1, pp. 83–88].	0.75
—	**Total**	**2.00**
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	Section 2. Z-transformation	
1.	Topic 2.1. Direct bilateral Z-transform Laplace transform for continuous-time signals. Complex plane of the operator method. Laurent series and bilateral Z-transform. Relationship between Z-transform and DFT. Complex plane in the Z-transform method and unit circle in the DFT method. Concept of the region of convergence (ROC) of the Z-transform. Form of the ROC boundaries. Criterion for the existence of the Z-image. Representation of the Z-transform by a rational function. The concept of zeros and poles of the Z-transform. Map of zeros and poles, Z-transform and CO for right-sided and left-sided exponential sequences. Sum of two exponential sequences (different cases). [1, pp. 111–120].	1.0
	Topic 2.2. Region of convergence of the Z-transform Form of OZ. Criterion for the existence of DCPF through OZ Z-transformation. Poles of Z-form and its OZ. OZ Z-transformation of a limited signal of finite duration. Z-transform of a right-sided sequence. Z-transform of a left-sided sequence. Z-transform of a bilateral sequence. Connectivity of Z-transform. Table of Z-transform and Z-transform for some signals. Stability, determinism, and OZ. [1, pp. 120–127].	1.0
—	**Total**	**2.00**
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1	Topic 2.3. Inverse Z-transform Tabular method. Method of simple fractions. Device for rational functions of the second degree. Decomposition formulas for different cases. Expansion into power series. Sequences of finite length. [1, pp. 127–134].	0.5
	Topic 2.4. Properties of Z-transformation Linearity. Delay. Multiplication by an exponential sequence. Differentiation in time space. Conjugate of a complex sequence. Time reversal. Convolution of a sequence. Initial value theorem. [1, pp. 134–142].	1.5
—	**Total**	**2.00**
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	Section 3. Discretization of a continuous signal	

1.	Topic 3.1. The process of periodic discretization of a continuous signal. Periodic discretization. Discretization step. Discretization frequency. Ideal continuous-discrete transformation (CDT). [1, pp. 154–156].	0.50
	Topic 3.2. Frequency representation of the discretization process Multiplicative modulation of a continuous signal by a periodic chain of Dirac delta functions and convolution of their Fourier images (NCPF) in frequency space. Periodic repetition of spectra. Superposition of spectra, their distortion, and the appearance of spurious frequencies at different sampling frequencies. Nyquist's theorem. Nyquist frequency. The relationship between the Fourier image of the DCT and the Fourier image of the FFT. Anti-aliasing filtering of real signals before discretization. Discretization and reconstruction of a sinusoidal signal. Subdiscretization. Spectrum superposition during sinusoidal signal reconstruction. [1, pp. 156–162].	0.25
	Topic 3.3. The process of restoring a narrowband continuous signal based on its readings IX ideal continuous low-pass filter for signal restoration. Interpolation of discrete signal values between readings. Samples of a discrete signal as weighting coefficients of ideal reconstructive orthogonal basis functions of Nyquist in the inverse Nyquist transform (inverse generalized PF in the Nyquist basis), and as a result of the direct Nyquist transform from a continuous signal (direct generalized PF in the Nyquist basis). Ideal discrete-to-continuous converter (DCC). [1, pp. 162–166].	0.50
	Topic 3.4. Processes of transforming spectrum-limited continuous signals in DCT-DS-DCT (DCT) systems Discrete processing of continuous signals and block diagram of an NDN system. Application of LSS in NDN systems. Effective frequency response of a virtual continuous LSS equivalent to an NDN system. Ideal continuous LPF with built-in discrete filter. Discrete implementation of an ideal continuous narrowband differentiator. Impulse invariance of a continuous LSS and an equivalent DSP system. Impulse invariance, continuous LPF, and equivalent discrete LPF. Impulse invariance and continuous system with rational system function. [1, pp. 166–175].	0.75
—	**Total**	**2.00**
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1.	Topic 3.5. Processes of converting discrete signals in DNP-NS-NDP (DND) systems Continuous processing of discrete signals, block diagram of a DND system, and basic equations of its operation. Non-integer delay. Moving average with non-integer delay. [1, pp. 175–179].	0.25
	Topic 3.6. Changing the sampling frequency of a signal without restoring its continuous form Reducing the sampling frequency by an integer number of times. Increasing the sampling frequency by an integer number of times. Changing the sampling frequency by a rational factor. [1, pp. 179–190].	1.00
	Topic 3.7. Processes of converting continuous signals with variable sampling frequency (multi-speed signals) Changing the order of spectrum limiting processes and lowering/raising the sampling frequency. The process of multiphase decomposition of a discrete signal. Multiphase implementation of the thinning process. Multiphase implementation interpolation process. [1, pp. 190–197].	0.75
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1	Topic 3.8. Processes of converting unlimited analog signals in ND systems Preliminary spectrum limitation to eliminate the effect of overlapping. Conversion of an analog continuous signal into a digital signal. Analysis of quantization errors. Conversion of a digital signal into an analog signal — continuous. [1, pp. 197–214].	1.0
	Topic 3.9. High-frequency sampling processes and noise generation in ADCs and DACs The process of ADC with increased sampling frequency and simple quantization. The process of ADC with increased sampling frequency and noise generation. DAC process with increased sampling frequency and noise generation. [1, pp. 214—227].	1.0
—	**Total**	**2.00**
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	Chapter 4. Analysis of processes in linear stationary systems of discrete time	
1.	Topic 4.1. Complex frequency response of a discrete linear stationary system Ideal spectrum limitation. Phase distortion and delay. [1, pp. 254–258].	0.5
	Topic 4.2. Characteristic functions of systems represented by linear difference equations with constant coefficients Stability and determinism. Inverse systems. Impulse response of discrete systems with rational characteristic function. [1, pp. 258–267].	1.5
—	**Total**	**2.00**
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1	Topic 4.3. Transfer functions of discrete systems with rational transfer functions in the case of a single zero or pole of the transfer function. Examples from multiple poles or zeros. [1, pp. 267–281].	1.5
	Topic 4.4. The relationship between ACF and FCF The concept of minimum phase. Inverse transformation of the complex plane with respect to the unit circle. [1, pp. 281–285].	0.25
	Topic 4.5. Discrete systems with constant AFC Systems with constant frequency response of the 1st and 2nd order. [1, pp. 285–290].	0.25
—	**Total**	**2.0**
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1	Topic 4.6. Minimum-phase discrete systems Decomposition of complex systems into minimum-phase and constant frequency response systems. Compensation for frequency response distortion in discrete linear stationary systems. Properties of minimum phase systems. [1, pp. 290–300]	1.0
	Topic 4.7. Discrete linear systems with generalized linear phase Systems with linear phase. Generalization of linear phase. Deterministic systems with generalized linear phase. Relationship between linear-phase SIH systems and minimum-phase systems. [1, pp. 300–318].	1.0
—	**Total**	**2.00**
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	Chapter 5. Discrete Fourier Transform	

	Topic 5.1. Discrete Fourier series: representation of periodic sequences Representation of periodic sequences of DC through discrete Fourier series (DFS). A finite number of periodic complex exponents of DC with the same period and finiteness of DFT terms. Determination of decomposition coefficients (analysis equation). An infinite number of periodic values of DC frequencies leading to the same periodic complex exponents, periodicity of the sequence of decomposition coefficients. Reconstruction of the periodic signal of the DC using the coefficients of the FFT (synthesis equation). DFT of a periodic chain of unit pulses. Duality of the form of the DC sequence and the form of the DFT coefficient sequence. DFT of a periodic sequence of rectangular pulses. [1, pp. 548–552].	0.5
	Topic 5.2. Properties of DRF Linearity. Sequence shift. Duality of time and frequency space. Symmetry. Periodic convolution. Overview of the properties of representing periodic sequences in the form of an FFT. [1, pp. 552–557].	0.5
1.	Topic 5.3. Fourier transform of periodic signals Presentation of DRF coefficients in the form of a line spectrum only at discrete frequencies. Non-summability of periodic signals, either absolutely or by square, and the absence of their DFT. Application of the Dirac delta function with a continuous argument for the conditional representation of periodic signals in the form of a continuous and periodic Fourier image in terms of frequency. Inverse DFT of the proposed conditional Fourier image of periodic signals. DFT for a periodic chain of unit pulses. Periodic extension of a finite duration signal (FD). Consideration of the periodic sequence of DRF coefficients of the periodically extended ST signal as a result of uniform discretization of the Fourier image of the primary ST signal. The relationship between DRF coefficients and the DFT function of one signal period. [1, pp. 557—561].	0.5
	Topic 5.4. Discretization of the Fourier image The Fourier image of an arbitrary non-periodic DC signal as an FSG that is continuously defined on a unit circle of the complex plane. Dividing the unit circle into N parts and determining the FSG at the vertices of the inscribed regular N-gon with the formation of a periodic sequence of values — the DRF coefficients of a given periodic signal DC — the result of the superposition of the periodic repetition of the original non-periodic signal. An equivalent description of the process of discretization of a Fourier image through discrete convolution of a non-periodic signal and a periodic sequence of single pulses. The frequency of discretization of a Fourier image and the conditions for undistorted periodic continuation of the signal. [1, pp. 561–565].	0.5
—	**Total**	**2.00**
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1.	Topic 5.5. Discrete Fourier transform as a method of representing sequences of finite duration Undistorted periodic extension of CT sequences. Representation of the resulting periodic extension of the signal as a finite set of DRF coefficients, — DFT coefficients. DFT coefficients as an estimate of the Fourier transform of the CT signal image at the vertices of a regular N-gon inscribed in a unit circle. Formulas for direct and inverse DFT. Interpolation of DFT coefficients by increasing the vertices of the N-gon (repeating the CT signal with a longer period). DFT of a rectangular pulse. [1, pp. 565–569].	1.0
	Topic 5.6. Properties of the DFT Linearity. Cyclic shift of sequences. Duality of time and frequency space. Symmetry. Cyclic convolution. Overview of the properties of representing periodic sequences in the form of DFT. [1, pp. 569–580].	1.0
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1.	Topic 5.7. Calculating linear convolution using DFT Linear convolution of two finite sequences. Cyclic convolution as linear with the effect of overlapping samples in time. Implementation of discrete linear stationary systems via DFT. [1, pp. 580–591].	1.0
	Topic 5.8. Discrete cosine transform Definition of discrete cosine transform. Definition of DCT-1 and DCT-2. Relationship between DFT and DCT-1. Relationship between DFT and DCT-2. Energy compression in DCT-2. Application of DCT. [1, pp. 591–602].	1.0
—	**Total**	**2.00**
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	Section 6. Application of DFT to Fourier Analysis	
1.	Topic 6.1. DFT and Fourier analysis of signals Stages of continuous signal processing using DFT analysis. Imperfection of the anti-aliasing filter. Jitter during discretization. Quantization noise. Purpose and use of weighting windows. Spectrum spreading and side lobe level from the window function. Fourier analysis using DFT. [1, pp. 695—699].	0.5
	Topic 6.2. DFT analysis of harmonic signals The effect of windowing. Spectral discretization. Effects of spectral discretization. [1, pp. 699–715].	1.5
—	**Total**	**2.00**
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1.	Topic 6.3. Time-dependent DFT The effect of window processing in the FFT. Discretization in time and frequency. [1, pp. 715–723].	1.0
	Topic 6.4. Block convolution using the FFT [1, pp. 723–724].	0.25
	Topic 6.5. Fourier analysis of non-stationary signals Time-dependent Fourier analysis of speech signals. Time-dependent Fourier analysis of radar signals. [1, pp. 724–730].	0.75
—	**Total**	**2.0**
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1.	Topic 6.6. Fourier analysis of stationary random signals: periodogram Periodogram. Properties of periodograms. Averaging periodograms. Calculating averaged periodograms using DFT. Example of periodogram analysis. [1, pp. 730–743].	1.0
	Topic 6.7. Spectral analysis of random signals through autocorrelation function estimates Calculation of correlation and estimation of the power spectrum using FFT. Example of estimation power spectrum through autocorrelation sequence estimation. [1, pp. 743–755].	1.0
—	**Total**	**2.00**
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	Section 7. Discrete Hilbert transform	
1.	Topic 7.1. Introductory provisions. [1, pp. 778–720].	0.25
	Topic 7.2. Real and imaginary parts of the Fourier image of a deterministic sequence. [1, pp. 780–785].	0.5
	Topic 7.3. Sufficiency theorems for finite sequences. [1, pp. 785–791].	0.5
	Topic 7.4. The relationship between absolute value and phase. [1, pp. 791–792].	0.25
	Topic 7.5. The relationship between the real and imaginary parts of analytic sequences through Hilbert transformation Designing a Hilbert transform. Representation of band signals. Band discretization. [1, pp. 792–804]. **Assignment of tasks for RGR, RR, GR, DZ, DKR**	0.5
—	**Total**	**2.0**
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The structure of lectures for ZFN differs in that the time allocated for each of the 18 lectures listed above is reduced, and the number of lectures is halved.

5.5. Laboratory classes (computer workshops)

The purpose of laboratory work is to study methods and acquire skills in experimental research of signal conversion processes in linear and nonlinear radio engineering circuits and to practically verify the response of circuits to a given action and its compliance with theoretically determined results.

The structure of laboratory classes for a total of 18 hours is shown in the table.

No.	Name of laboratory work	Number of aud. hours
1.	**Signal conversion processes in interstation signaling devices using *DTMF***: Encoding of information to be transmitted and synthesis of ***DTMF*** signals in discrete time: • Processes of synthesis, encoding, modulation, demodulation, and decoding of *DTMF* signals: 0 in devices for tone dialing of a subscriber's telephone number, 0 in automatic subscriber telephone number identification devices. [23]	3
1.	**Signal conversion processes in interstation signaling devices using *DTMF***: Demodulation of ***DTMF*** signals in discrete time and decoding of transmitted information: • processes of synthesis, encoding, modulation, demodulation, and decoding of *DTMF* signals: 0 in devices for tone dialing of a subscriber's telephone number, 0 in automatic subscriber telephone number identification devices. [23]	3
1.	**Signal conversion processes in modems with complex modulation types**: Encoding of information to be transmitted and synthesis of modulated signals in discrete time: • *BFSK* in *V*.21 modems, circular *BPSK* and *QPSK* in *V*.22 modems, • rectangular QAM-16 in *V.22bis* modems, • ring *QPSK* and *π/4-QPSK* in *V*.26 modems, ring *8-PSK* in *V*.27 modems, • ring QAM-16, QAM-8, *QPSK* with non-redundant coding in the modem *V*.29, rectangular QAM-16 with non-redundant coding and rectangular QAM-32 with redundant lattice coding in the *V*.32 modem. [23]	3
1.	**Signal conversion processes in modems with complex modulation types**: Demodulation of modulated signals in discrete time and decoding of transmitted information: • *BFSK* in *V*.21 modems, circular *BPSK* and *QPSK* in *V*.22 modems, • rectangular QAM-16 in *V.22bis* modems, • ring *QPSK* and *π/4-QPSK* in *V*.26 modems, ring *8-PSK* in *V*.27 modems, • ring QAM-16, QAM-8, *QPSK* with non-redundant coding in the modem *V*.29 modem, rectangular QAM-16 with non-redundant coding and rectangular QAM-32 with redundant lattice coding in the *V*.32 modem. [23]	3
1.	**Classical methods for estimating AC, FS, EC, and AKF signals of discrete time**	3
1.	**Study of the spread of discrete-time signal spectra with limited observation duration**	3
1.	**Spectral estimation of signals in distance measurements using the LCM radar. Study of classical CSA methods**. [23]	0
1.	**Spectral estimation of signals in distance measurements using the LCM radar method. Research and parametric methods of with increased resolution**. [23]	0
	Total	18.00

6. Independent work by students

5.7. Independent work

Students must prepare in advance for lectures, practical and laboratory classes (computer workshops). Before lectures, it is necessary to review the theoretical material provided in previous lectures. Before practical and laboratory classes (computer workshops), it is necessary to review the relevant theoretical material.

It is mandatory to complete individual assignments for computer workshops, which must be completed before the next laboratory class. To prepare for individual assignments, students should use the recommended literature and lecture notes.

To better consolidate the theoretical material, students must complete thematic and modular tests (in *the Moodle* LMS), the preparation for which requires careful review of the theoretical material from the relevant lectures during independent study hours.

Independent work by students is expected during preparation for all types of classroom activities and tests according to the standards presented in the table.

No. No	Title of the topic for independent study	Number of hours of independent study
1.	**Section 1. Discrete signals and discrete systems** [1, Chapter 2. pp. 28-110] Topic 1.1. Discrete signals as sequences [1, pp. 28-30]. Standard sequences and operations on them [1, pp. 30-35].	0.75
1.	Topic 1.2. Types of discrete systems and their definition through discrete signal conversion processes. (Systems with and without memory. Linear and nonlinear systems. Stationary (time-invariant) and non-stationary systems. Deterministic and non-deterministic systems. Stable and unstable systems) [1, pp. 35–42].	1.00
1.	Topic 1.3. Discrete convolution as a process of signal conversion in linear stationary (LTI) systems [1, pp. 42–47].	1.00
1.	Topic 1.4. Properties of the discrete convolution process [1, pp. 47–53].	1.00
1.	Topic 1.5. Representation of discrete signal conversion processes in LIC systems as linear difference equations with constant coefficients [1, pp. 53–59].	1.00
1.	Topic 1.6. Representation of discrete signals and processes in discrete-time systems in the frequency domain. (Complex exponent as an eigenfunction and BFR as an eigenvalue of a discrete linear stationary system. Steady-state and transient responses of a discrete linear stationary deterministic system to an instantaneously applied discrete complex exponent). [1, pp. 59–67].	1.25
1.	Topic 1.7. Discrete-time Fourier transform (DTFT) [1, pp. 67–74].	1.50
1.	Topic 1.8. Symmetries of the DFT [1, pp. 74–77].	1.25
1	Topic 1.9. Theorems about DCT. (Linearity of DCT. Time and frequency shifts. Time reversal. Differentiation in the frequency domain. Parseval's theorem. Theorem about discrete convolution. Modulation, or theorem about discrete periodic convolution theorem). [1, pp. 77–83].	1.00
1.	Topic 1.10. Random discrete signals. [1, pp. 83–88].	1.25
1.	**Section 2. Z-transformation** [1, Chapter 3. pp. 111–153] Topic 2.1. Direct bilateral Z-transformation [1, pp. 111–120].	1.75
1.	Topic 2.2. Region of convergence of Z-transformation [1, pp. 120–127].	1.75
1.	Topic 2.3. Inverse Z-transform. (Tabular method. Method of simple fractions. Expansion into power series). [1, pp. 127–134].	2.0

1.	Topic 2.4. Properties of Z-transformation. (Linearity. Delay. Multiplication by an exponential sequence. Differentiation in time space. Conjugate of a complex sequence. Time reversal. Convolution of a sequence. Initial value theorem). [1, pp. 134–142].	2.50
1.	**Section 3. Discretization of a continuous signal** [1, Chapter 4. pp. 154–253] Topic 3.1. The process of periodic discretization of a continuous signal [1, pp. 154–156].	1.25
1.	Topic 3.2. Frequency representation of the discretization process [1, pp. 156–162].	1.50
1.	Topic 3.3. The process of restoring a narrowband continuous signal by its readings [1, pp. 162–166].	1.25
1.	Topic 3.4. Processes of transforming spectrum-limited continuous signals in NDN systems. (Linear stationary systems. Impulse invariance) [1, pp. 166–175].	0.75
1.	Topic 3.5. Processes of transforming discrete signals in DND systems [1, pp. 175–179].	0.50
1.	Topic 3.6. Changing the sampling frequency of a signal without restoring its continuous form. (Reducing the sampling frequency by an integer number of times. Increasing the sampling frequency by an integer number of times. Changing the sampling frequency by a rational factor). [1, pp. 179–190].	1.50
1.	Topic 3.7. Processes of converting continuous signals with variable sampling frequencies (multi-speed signals). (Changing the order of spectrum limiting processes and lowering/raising the sampling frequency. The process of multiphase decomposition of a discrete signal. Multiphase implementation of the thinning process. Multiphase implementation of the interpolation process). [1, pp. 190–197].	1.75
1.	Topic 3.8. Processes of converting unlimited analog signals in ND systems. (Preliminary spectrum limiting to eliminate the overlapping effect. Conversion of an analog continuous signal into a digital one. Analysis of quantization errors. Conversion of a digital signal into an analog continuous signal.) [1, pp. 197–214].	1.25
1.	Topic 3.9. High-frequency sampling processes and noise generation in ADCs and DACs. (The process of ADC with increased sampling frequency and simple quantization. The process of ADC with increased sampling frequency and noise generation. The process of DAC with increased sampling frequency and noise generation). [1, pp. 214–227].	1.25
1.	**Section 4. Analysis of processes in linear stationary discrete-time systems** [1, Chapter 5. pp. 254-345] Topic 4.1. Complex frequency response of a discrete linear stationary system. (Ideal spectrum limitation. Phase distortion and delay). [1, pp. 254–258].	0.65
1.	Topic 4.2. Characteristic functions of systems represented by linear difference equations with constant coefficients. (Stability and determinism. Inverse systems. Impulse response of discrete systems with rational characteristic function). [1, pp. 258–267].	0.75
1.	Topic 4.3. Frequency response of discrete systems with rational characteristic function. (Frequency response in the case of a single zero or pole of the characteristic function. Examples with multiple poles or zeros). [1, pp. 267–281].	0.75
1.	Topic 4.4. The relationship between the frequency response and the phase response. [1, pp. 281–285].	0.35
1.	Topic 4.5. Discrete systems with constant AFC [1, pp. 285–290].	0.35
1.	Topic 4.6. Minimum-phase discrete systems. (Decomposition of complex systems into minimum-phase and constant frequency response systems. Compensation for frequency response distortions in discrete linear stationary systems. Properties of of minimum phase systems). [1, pp. 290–300]	0.70
1.	Topic 4.7. Discrete linear systems with generalized linear phase. (Systems with linear phase. Generalization of linear phase. Deterministic systems with generalized linear phase. Relationship between linear-phase SIH systems with minimum-phase systems). [1, pp. 300–318].	0.45

1.	**Section 5. Discrete Fourier transform** [1, Chapter 8. pp. 548-629] Topic 5.1. Discrete Fourier series: representation of periodic sequences. [1, pp. 548–552].	0.65
1.	Topic 5.2. Properties of the DFT. (Linearity. Sequence shift. Duality of time and frequency space. Symmetry. Periodic convolution. Overview of the properties of representing periodic sequences in the form of the DFT). [1, pp. 552–557].	0.80
1.	Topic 5.3. Fourier transform of periodic signals. [1, pp. 557–561].	0.65
1.	Topic 5.4. Discretization of the Fourier image. [1, pp. 561–565].	0.65
1.	Topic 5.5. Discrete Fourier transform: representation of finite sequences. [1, pp. 565–569].	0.65
1.	Topic 5.6. Properties of DFT. (Linearity. Cyclic shift of a sequence. Duality of time and frequency space. Symmetry. Cyclic convolution. Overview of the properties of representing periodic sequences in the form of DFT). [1, pp. 569–580].	0.80
1.	Topic 5.7. Calculation of linear convolution using DFT. (Linear convolution of two finite sequences. Cyclic convolution as linear with the effect of overlapping readings in time. Implementation of discrete linear stationary systems via DFT). [1, pp. 580–591].	0.90
1.	Topic 5.8. Discrete cosine transform. (Definition of discrete cosine transform. Definition of DCT-1 and DCT-2. Relationship between DFT and DCT-1. Relationship between DFT and DCT-2. Energy compression in DCT-2. Application of DCT). [1, pp. 591–602].	1.90
1.	**Section 6. Application of DFT to Fourier analysis** [1, Chapter 10. pp. 695–777] Topic 6.1. DFT and Fourier analysis of signals. [1, pp. 695–699].	0.9
1.	Topic 6.2. DFT analysis of harmonic signals. (The effect of windowing. Spectral discretization). [1, pp. 699–715].	0.85
1.	Topic 6.3. Time-dependent DFT. (Window processing effect in ZCH DFT. Discretization in time and frequency). [1, pp. 715–723].	0.65
1.	Topic 6.4. Block convolution using ZF DFT. [1, pp. 723–724].	0.55
1.	Topic 6.5. Fourier analysis of non-stationary signals. (Time-dependent Fourier analysis of speech signals. Time-dependent Fourier analysis of radar signals). [1, pp. 724–730].	0.50
1.	Topic 6.6. Fourier analysis of stationary random signals: periodogram. (Periodogram. Properties of periodograms. Averaging of periodograms. Calculation of averaged periodograms using DFT. Example periodogram analysis). [1, pp. 730–743].	0.50
1.	Topic 6.7. Spectral analysis of random signals through autocorrelation function estimates. (Correlation calculation and power spectrum estimation through DFT. Example of power spectrum estimation through autocorrelation sequence estimation the autocorrelation sequence). [1, pp. 743–755].	1.05
1.	**Section 7. Discrete Hilbert transform** [1, Chapter 11. pp. 778-813] Topic 7.1. Introductory provisions [1, pp. 778–720].	0.50
1.	Topic 7.2. Real and imaginary parts of the Fourier image of a deterministic sequence [1, pp. 780–785].	1.
1.	Topic 7.3. Sufficiency theorems for finite sequences [1, pp. 785–791].	1.
1.	Topic 7.4. The relationship between absolute value and phase [1, pp. 791–792].	0.50
1.	Topic 7.5. The relationship between the real and imaginary parts of analytic sequences through Hilbert transformation. (Designing a Hilbert transformer. Representation of band signals. Band discretization). [1, pp. 792–804].	1.0
	Total	**50.00**
1.	Thematic assignment 1 in *Moodle* on topic 1.1 [23].	0.5
1	Thematic CR 2 in *Moodle* SDN on topic 1.2 [23].	0.50
1.	Thematic CR 3 in *Moodle* SDN on topics 1.3 and 1.4 [23].	0.50
1.	Thematic CR 4 in *Moodle* SDN on topics 1.5 [23].	0.25
1.	Thematic CR 5 in *Moodle* SDN on topics 1.6 and 1.7 [23].	0.5
1.	Thematic assignment 6 in *Moodle* on topics 1.7 and 1.8 [23].	0.25

1	Thematic CR 7 in *Moodle* SDN on topics 1.7 [23].	0.5
1	Thematic CR 8 in *Moodle* SDN on topic 1.8 [23].	0.50
1.	Thematic CR 9 in *Moodle* SDN on topic 1.9 [23].	0.50
1.	Modular coursework in *Moodle* for section 1, topics 1-5 [23].	1.
1.	Modular coursework in *Moodle* for section 1, topics 6-9 [23].	1.
1.	Modular course in *Moodle* according to section 2 [23].	0.0
1	Modular coursework in *Moodle* for section 3 [23].	0.
1	Modular coursework in *Moodle* for section 4 [23].	0.0
1	Modular coursework in *Moodle* for section 5 [23].	0.0
1	Modular coursework in *Moodle* for section 6 [23].	0.0
1	Modular coursework in *Moodle* for section 7 [23].	0.0
1	DCR	10.
1	RGR	0.0
1.	**Coursework** [23]	0.0
1.	**Preparation for the exam**	0.
	Total	**66.00**

Policy and control

7. Academic discipline (educational component) policy

6.1. Class attendance

Attendance at lectures, practical classes, and laboratory classes is mandatory in accordance with the Regulations on the Organization of the Educational Process at Igor Sikorsky KPI. In case of illness, the student is required to submit a duly completed certificate of the duration of treatment from the institution where the treatment was provided. In other cases (e.g., family circumstances), the issue is resolved on an individual basis with the instructor. Material from classes that were missed for one reason or another must be mastered independently. To assist students, the SDN dtsp.kiev.ua contains links to video recordings of all lectures.

6.2. Missed tests

The submission of the results of simulation work, TKR, and MKR is mandatory. Late submission will result in a zero grade. In case of late submission for valid reasons (e.g., illness) confirmed by relevant documents, the student has the opportunity to take the test at another time agreed with the teacher without a grade reduction. For the purpose of self-improvement and improving one's own results, it is allowed to retake the TKR and MKR.

A missed exam will not be counted regardless of the reasons for the absence; in this case, the student will receive a "no show" mark and must take the exam during an additional session.

6.3. Announcement of test results

The results of independent work are entered into the Moodle LMS and announced to each student individually in person or remotely, accompanied by assessment sheets (in the Moodle LMS) in which students can see their grades according to specific criteria, as well as the main mistakes and comments on them.

The results of the written exam are indicated on the forms for the written exam (tasks performed by students) with an indication of all errors, correct or incorrect answers, as well as comments, remarks, etc. The exam can be conducted in the form of tests and tasks using the capabilities of the Moodle LMS.

6.4. Academic integrity

The policy and principles of academic integrity are defined in Section 3 of the Code of Honor of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute." For more details, see: https://kpi.ua/code.

6.5. Standards of ethical behavior

The standards of ethical conduct for students and employees are defined in Section 2 of the Code of Honor

of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". For more details, see: https://kpi.ua/code.

6.6. Procedure for appealing the results of control measures

Students have the opportunity to ask any questions regarding the procedure for conducting and/or evaluating control measures and expect that they will be considered in accordance with pre-defined procedures.

Students have the right to appeal the results of control measures, but they must provide a reasoned explanation of which criteria they disagree with according to the assessment sheet and/or comments.

8. Types of assessment and the learning outcomes assessment rating system (LOAS)

1. Task completion and student ratings are recorded in the Moodle DTSP.KIEV.UA learning management system. From the first day of the course, students create personal profiles in the learning management system and gain access to all course materials, including the rules of the rating system and their own grade book.

2. The student's rating for the credit module is calculated on a 100-point scale (100% success rate)

$R_m = R_s + R_e = 100;$

$R_{smax} = 60$; $R_{emax} = 40$.

The starting rating R_s(semester component) consists of points that the student receives for: •

completing laboratory (simulation) tasks;
• completing modular tests;
• completion of thematic tests;
• completing computational and graphical tasks (or DCR); •
additional activities.

3. Completion, formatting, and defense of reports on the completion of laboratory work (LR) (computer workshops), which provide the following performance rating points:

Completion of laboratory work (computer workshop)	40%
Preparation of a report in accordance with the requirements	20
Report formatting with violations	0...10
Complete answer (at least 90% of the required information) during protection of LR in the current or next laboratory session	40%
Incomplete answer (at least 60% of the required information and some errors) or untimely defense of the LR	20
Answer with significant errors	10
Unsatisfactory answer	0

The contribution of LR points to the semester component of the rating is 25%.

Completion of thematic and modular control works (TCW and MCW) with manual assessment:

Complete answer (at least 90% of the required information)	95…100
Sufficiently complete answer (at least 75% of the required information or minor inaccuracies)	75–94
Incomplete answer (at least 60% of the required information and some errors)	60...74%
Unsatisfactory answer	0...59

Contribution to the semester component of the rating points for TKR and MKR (theoretical classes) - 35%

Contribution to the semester component of the rating points for tests and homework (practical classes) - 25%

4. The condition for *a* positive *first assessment* is to obtain a current rating of at least 60% (60 points) (provided that all TCR and other planned tasks are completed by the time of assessment). The condition for *a* positive *second assessment* is to obtain a current rating of at least 60% (60 points) (provided that all MCRs and other planned tasks are completed by the time of assessment).

5. The condition for admission to the exam is the completion of all laboratory work (computer practicals), calculation work, and a starting rating of at least 60% (60 points).

6. During the exam, students complete a written test. Each task contains two theoretical questions and one calculation task. The list of exam tasks is available on the MOODLE website for the discipline.

Each theoretical question is worth 30% of the maximum exam score, and the calculation task is worth 40% of the final grade.

In conclusion

R_e = 2´30 + 40 = 100% success rate = 40 points (exam component).

7. The sum of the starting points and the points for the exam test is converted to an exam grade according to the table:

Points	Grade
100…95	Excellent
94	Very good
84	Good
74…65	Satisfactory
64	Sufficient
Less than 60	Unsatisfactory
There are uncredited modeling tasks or uncredited module test	Not admitted

Table of correspondence between rating points and university scale grades

Number of points	Grade
100-95	Excellent
94	Very good
84	Good
74-65	Satisfactory
64-60	Sufficient
Less than 60	Unsatisfactory
Conditions for admission not met	Not admitted

9. Additional information on the discipline (educational component)

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Description of material, technical, and informational support for the discipline

Practical and laboratory classes in the discipline "Discrete and Digital Signals and Processes in Radio Engineering" are conducted on PCs using the Matlab package.

Practical and laboratory work is carried out in computer classroom 321-17, and testing of the results of laboratory work is carried out in specialized laboratory 318-17.

There are 12 workstations in classroom 321-17. Each workstation is equipped with a personal computer, an Ethernet socket, and a 220 V outlet for connecting additional equipment. Three six-hour laboratory works have been prepared.

There are 6 workstations in laboratory 318-17. Each workstation is equipped with various generators, an oscilloscope, and voltmeters.

While studying the discipline "Discrete and Digital Signals and Processes in Radio Engineering," students perform the following laboratory work:
LR 1. Signal conversion processes in interstation signaling devices using DTMF:
- processes of synthesis, encoding, modulation, demodulation, and decoding of DTMF signals in devices for tone dialing of a subscriber's telephone number,
- processes of synthesis, encoding, modulation, demodulation, and decoding of DTMF signals in automatic subscriber telephone number identification devices.

LP 2. Signal conversion processes in modems with complex modulation types:
- BFSK in a V.21 modem,
- ring BPSK and QPSK in a V.22 modem,
- rectangular QAM-16 in the V.22bis modem,
- ring QPSK and π/4-QPSK in the V.26 modem,
- circular 8-PSK in V.27 modems,
- ring QAM-16, QAM-8, QPSK with non-redundant coding in V.29 modems,
- rectangular QAM-16 with non-redundant coding and rectangular QAM-32 with redundant

lattice coding in the V.32 modem.

LP 3. Research on methods for estimating the spectrum and spectral parameters of a signal in the presence of additive interference and quantization noise:
- familiarization with the principle of operation of a radio rangefinder when measuring distance using the LFM (linear frequency modulation) method,
  - familiarization with classical and parametric methods of DSA (digital spectral analysis),
- researching ways to implement classical methods of spectrum estimation using the spectral density function,
  - investigating the effect of line spectrum spreading of a periodic signal with limited observation time,
- investigating the effect of the process of coherent accumulation of signal realizations on the characteristics of DSA methods in noisy conditions,
- research on the effect of increasing the virtual bit depth of the quantization process during coherent accumulation of the realization of a mixture of signal and "rocking" noise.

Conversion of signals from continuous form to discrete and vice versa, as well as their analysis is carried out using ADCs, DACs, oscilloscopes, and spectrum analyzers (for audio range signals, PC audio cards and evaluation modules based on the ADSP-2181 signal processor can be used; for RF range signals, ADCs and DACs with RF sampling can be used, and data synthesis and analysis is provided by PC tools).

Work program for the academic discipline (syllabus):
Compiled by Pavlov O. I.;
Approved by the RI Department (Minutes No. 06/2024 dated 06/27/2024)
Approved by the methodological commission of the faculty/research institute (protocol No. 06/2024 dated 28.06.2024)